section *Types* parents *standard_toolkit*

$BOOL ::= True \mid False$

$[LABEL]$

section *ApplicationModel* parents *Types*

$CARDINALITY ::= One \mid Many$

$[ATYPE]$

CLASS
$label : LABEL$

$NULLCLASS : CLASS$

ATTRIBUTE
$optional : BOOL$
$upper : CARDINALITY$
$type : ATYPE$
$label : LABEL$

ATTRIBUTEOfCLASS
$class : CLASS$
$attribute : ATTRIBUTE$

ASSOCIATION
$label : LABEL$
$upper : CARDINALITY$
$optional : BOOL$
$source : CLASS$
$target : CLASS$

INHERITANCE
$parent : CLASS$
$child : CLASS$

ENTITIES

$$
\begin{aligned}
&classes : \mathbb{P}\, CLASS \\
&attributes : \mathbb{P}\, ATTRIBUTE \\
&associations : \mathbb{P}\, ASSOCIATION \\
&attributesOfClasses : \mathbb{P}\, ATTRIBUTEOfCLASS \\
&inheritance : \mathbb{P}\, INHERITANCE
\end{aligned}
$$

$$ERRENTITIES : ENTITIES$$

section *ApplicationHelpers* parents *ApplicationModel*

initEntity

$$
\begin{aligned}
&c! : CLASS \\
&l? : LABEL \\
\hline
&c!.label = l?
\end{aligned}
$$

initEntities

$$
\begin{aligned}
&e? : ENTITIES \\
\hline
&e?.classes = \varnothing \\
&e?.attributes = \varnothing \\
&e?.associations = \varnothing \\
&e?.attributesOfClasses = \varnothing \\
&e?.inheritance = \varnothing
\end{aligned}
$$

initAttribute

$$
\begin{aligned}
&label? : LABEL \\
&upper? : CARDINALITY \\
&optional? : BOOL \\
&p! : ATTRIBUTE \\
\hline
&p!.label = label? \\
&p!.upper = upper? \\
&p!.optional = optional? \\
&p!.type \in ATYPE
\end{aligned}
$$

initAssociation

$label? : LABEL$
$upper? : CARDINALITY$
$optional? : BOOL$
$source?, target? : CLASS$
$a! : ASSOCIATION$

$a!.label = label?$
$a!.upper = upper?$
$a!.optional = optional?$
$a!.source = source?$
$a!.target = target?$

initInheritance

$i! : INHERITANCE$
$parent, child : CLASS$

$i!.parent = parent$
$i!.child = child$

initAttributeOfClass

$c? : CLASS$
$p? : ATTRIBUTE$
$poc! : ATTRIBUTEOfCLASS$

$poc!.class = c?$
$poc!.attribute = p?$

$$attributesOf : CLASS \times ENTITIES \to \mathbb{P}\, ATTRIBUTE$$

$$\forall\, c : CLASS;\ e : ENTITIES \bullet$$
$$attributesOf(c, e) = \{p : ATTRIBUTE \mid$$
$$p \in e.attributes \land \exists\, poc : ATTRIBUTEOfCLASS \bullet$$
$$poc.class = c \land poc.attribute = p\}$$

$$children : CLASS \times ENTITIES \to \mathbb{P}\, CLASS$$

$$\forall\, c_p : CLASS;\ s : ENTITIES \bullet$$
$$children(c_p, s) = \{c : CLASS \mid$$
$$\exists\, i : INHERITANCE \bullet i.parent = c_p \land i.child = c \land$$
$$i \in s.inheritance\}$$

$$parentOf : CLASS \times ENTITIES \to CLASS$$

$$\begin{aligned}
&\forall\, c_c, c_p : CLASS;\ s : ENTITIES \bullet \\
&\quad parentOf(c_c, s) = c_p \Leftrightarrow \exists\, i : INHERITANCE \bullet \\
&\qquad i.parent = c_p \land i.child = c_c \lor \\
&\quad parentOf(c_c, s) = NULLCLASS \Leftrightarrow \forall\, i : INHERITANCE \bullet \\
&\qquad i.parent = c_p \land i.child \neq c_c
\end{aligned}$$

$$childParentRelation : CLASS \times ENTITIES \to CLASS \to CLASS$$

$$\begin{aligned}
&\forall\, c_c, c_p : CLASS;\ s : ENTITIES \bullet \\
&childParentRelation(c_c, s) = \{c_c \mapsto c_p\} \Leftrightarrow c_p = parentOf(c_c, s)
\end{aligned}$$

$$parentChildRelation : CLASS \times ENTITIES \to \mathbb{P}\, CLASS \to CLASS$$

$$\begin{aligned}
&\forall\, c_c, c_p : CLASS;\ s : ENTITIES \bullet \\
&c_c \mapsto c_p \in childParentRelation(c_p, s) \Leftrightarrow c_p = parentOf(c_c, s)
\end{aligned}$$

$$isInheritanceCyclical : CLASS \times ENTITIES \to BOOL$$

$$\begin{aligned}
&\forall\, c : CLASS;\ s : ENTITIES \bullet \\
&\quad isInheritanceCyclical(c, s) = True \Leftrightarrow \\
&\qquad \exists\, par == childParentRelation(c, s) \bullet c \in \mathrm{ran}(par^+) \lor \\
&\quad isInheritanceCyclical(c, s) = False \Leftrightarrow \\
&\qquad \forall\, par == childParentRelation(c, s) \bullet c \notin \mathrm{ran}(par^+)
\end{aligned}$$

$$associationsTargeting : CLASS \times ENTITIES \to \mathbb{P}\, ASSOCIATION$$

$$\begin{aligned}
&\forall\, c : CLASS;\ s : ENTITIES;\ r : \mathbb{P}\, ASSOCIATION \bullet \\
&\quad associationsTargeting(c, s) = \\
&\qquad \{a : ASSOCIATION \mid a \in s.associations \land a.target = c\}
\end{aligned}$$

$$associationsOf : CLASS \times ENTITIES \to \mathbb{P}\, ASSOCIATION$$

$$\begin{aligned}
&\forall\, c : CLASS;\ s : ENTITIES;\ as : \mathbb{P}\, ASSOCIATION \bullet \\
&\quad associationsOf(c, s) = \\
&\qquad \{a : ASSOCIATION \mid a \in s.associations \land c = a.source\}
\end{aligned}$$

$$isReferenced : CLASS \times ENTITIES \to \mathbb{P}\, CLASS$$

$$\begin{aligned}
&\forall\, c : CLASS;\ e : ENTITIES \bullet \quad isReferenced(c, e) = \\
&\qquad \{cr : CLASS \mid cr \in e.classes \land \exists\, a : ASSOCIATION \bullet \\
&\qquad\quad a.source = cr \land a.target = c\}
\end{aligned}$$

addEntityEL

$\Delta ENTITIES$
$c? : CLASS$

$\forall\, c : CLASS \bullet$
$\quad c \in classes \Rightarrow c.label \neq c?.label$
$attributesOf(c?, \theta(ENTITIES)) = \varnothing$
$classes' = classes \cup \{c?\}$

removeEntityEL

$\Delta ENTITIES$
$c? : CLASS$

$c? \in classes$
$children(c?, \theta(ENTITIES)) = \varnothing$
$associationsTargeting(c?, \theta(ENTITIES)) = \varnothing$
$classes' = classes \setminus \{c?\}$

addAttributeEL

$\Delta ENTITIES$
$c? : CLASS$
$p? : ATTRIBUTE$
$poc : ATTRIBUTEOfCLASS$

$c? \in classes$
$\{p : ATTRIBUTE \mid p \in attributesOf(c?, \theta(ENTITIES)) \land$
$\quad p.label = p?.label\} = \varnothing$
$attributes' = attributes \cup \{p?\}$
$initAttributeOfClass[poc/poc!]$
$attributesOfClasses' = attributesOfClasses \cup \{poc\}$

removeAttributeEL

$\Delta ENTITIES$
$c? : CLASS$
$p? : ATTRIBUTE$
$poc : ATTRIBUTEOfCLASS$

$c? \in classes$
$p? \in attributes$
$poc \in attributesOfClasses$
$poc.class = c?$
$poc.attribute = p?$
$attributesOfClasses' = attributesOfClasses \setminus \{poc\}$
$attributes' = attributes \setminus \{p?\}$

addAssociationEL

$\Delta ENTITIES$
$a? : ASSOCIATION$

$\forall a : ASSOCIATION \bullet$
$\quad a \in associations \Rightarrow a.label \neq a?.label$
$a?.source \in classes$
$a?.target \in classes$
$associations' = associations \cup \{a?\}$

removeAssociationEL

$\Delta ENTITIES$
$a? : ASSOCIATION$

$a? \in associations$
$associations' = associations \setminus \{a?\}$

addEntityParentEL

$\Delta ENTITIES$
$i? : INHERITANCE$

$parentOf(i?.child, \theta(ENTITIES)) = NULLCLASS$
$children(i?.child, \theta(ENTITIES)) = \varnothing$
$\forall p_c, p_p : ATTRIBUTE \bullet$
$\quad p_c \in attributesOf(i?.child, \theta(ENTITIES)) \land$
$\quad p_p \in attributesOf(i?.parent, \theta(ENTITIES)) \Rightarrow$
$\quad p_p.label \neq p_c.label$
$\forall a_c, a_p : ASSOCIATION \bullet$
$\quad a_c.source = i?.child \land a_p.source = i?.parent \Rightarrow a_p.label \neq a_c.label$
$inheritance' = inheritance \cup \{i?\}$

removeEntityParentEL

$\Delta ENTITIES$
$c? : CLASS$

$\exists i : INHERITANCE \bullet$
$\quad i \in inheritance \land i.child = c? \land$
$\quad inheritance' = inheritance' \setminus \{i\}$

pushAttributeDownEL

$\Delta ENTITIES$
$\Delta CLASS$
$p? : ATTRIBUTE$
$poc : ATTRIBUTEOfCLASS$
$c : CLASS$

$c = \theta(CLASS)$
$c \in classes$
$p? \in attributesOf(c, \theta(ENTITIES))$
$[| \forall c' : CLASS \bullet$
$\quad c' \in children(c, \theta(ENTITIES)) \Rightarrow addAttributeEL[c'/c?]] \gg$
$removeAttributeEL[c/c?]$

pushAttributeDownToClassEL

$\Delta ENTITIES$
$\Delta CLASS$
$\Delta CLASS$
$p? : ATTRIBUTE$
$a, a', b, b' : CLASS$
$poc : ATTRIBUTEOfCLASS$

$a = \theta(CLASS)$
$a' = \theta(CLASS)'$
$a \in classes$
$b = \theta(CLASS)$
$b' = \theta(CLASS)'$
$b \in classes$
$a = parentOf(b, \theta(ENTITIES))$
$p? \in attributesOf(a, \theta(ENTITIES))$
$addAttributeEL[b/c?]$
$removeAttributeEL[a/c?]$

pullAttributeUpEL

$\Delta ENTITIES$
$\Delta CLASS$
$p? : ATTRIBUTE$
$poc : ATTRIBUTEOfCLASS$
$c, d : CLASS$

$p? \in attributes$
$d = parentOf(\theta(CLASS), \theta(ENTITIES))$
$c = \theta(CLASS)$
$addAttributeEL[d/c?] \gg removeAttributeEL[c/c?]$

pullCommonAttributeUpEL

$\Delta ENTITIES$
$p? : ATTRIBUTE$
$c_c? : CLASS$
$poc : ATTRIBUTEOfCLASS$
$d : CLASS$

$\exists\, d == parentOf(c_c?, \theta(ENTITIES)) \bullet$
  $\exists\, cs == children(d, \theta(ENTITIES)) \bullet$
    $\forall\, c : CLASS \bullet$
      $c \in cs \Leftrightarrow c \in children(d, \theta(ENTITIES)) \land$
      $p? \in attributesOf(c, \theta(ENTITIES)) \land$
      $removeAttributeEL[c/c?]$
  $addAttributeEL[d/c?]$

section *ApplicationInvariants* parents *ApplicationModel*, *ApplicationHelpers*

$\forall\, e : ENTITIES;\ c_1, c_2 : CLASS \bullet$
  $c_1 \in e.classes \land c_2 \in e.classes \land c_1.label = c_2.label \Rightarrow c_1 = c_2$

$\forall\, e : ENTITIES;\ poc_1, poc_2 : ATTRIBUTEOfCLASS \bullet$
  $poc_1 \in e.attributesOfClasses \land poc_2 \in e.attributesOfClasses \land$
  $poc_1.class = poc_2.class \land poc_1 \neq poc_2 \Rightarrow$
    $(poc_1.attribute).label \neq (poc_2.attribute).label$

$\forall\, e : ENTITIES;\ a_1, a_2 : ASSOCIATION \bullet$
  $a_1 \in e.associations \land a_2 \in e.associations \land$
  $a_1.label = a_2.label \Rightarrow a_1 = a_2 \lor a_1.source \neq a_2.source$

$\forall\, e : ENTITIES;\ c_1, c_2 : CLASS;\ par : \mathbb{P}\, CLASS;\ p_1 : ATTRIBUTE \bullet$
  $par = \mathrm{ran}(childParentRelation(c_1, e)^+) \land c_2 \in par \land c_1 \in e.classes \Rightarrow$
    $p_1 \in attributesOf(c_1, e) \land p_1 \notin attributesOf(c_2, e)$

$\forall\, e : ENTITIES;\ c_1, c_2 : CLASS;\ par : \mathbb{P}\, CLASS;\ a_1 : ASSOCIATION \bullet$
  $par = \mathrm{ran}(childParentRelation(c_1, e)^+) \land c_2 \in par \land c_1 \in e.classes \Rightarrow$
    $a_1 \in associationsOf(c_1, e) \land a_1 \notin associationsOf(c_2, e)$

$\forall\, e : ENTITIES;\ p : ATTRIBUTE \bullet$
  $p \in e.attributes \Leftrightarrow \exists\, poc : ATTRIBUTEOfCLASS \bullet$
    $poc \in e.attributesOfClasses \land p = poc.attribute$
$\forall\, e : ENTITIES;\ c : CLASS;\ poc : ATTRIBUTEOfCLASS \bullet$
  $c = poc.class \Rightarrow c \in e.classes$

$$\forall e : ENTITIES;\ a : ASSOCIATION \bullet$$
$$a \in e.associations \Rightarrow \exists c_s, c_t : CLASS \bullet$$
$$c_s = a.source \land c_t = a.target \land c_s \in e.classes \land c_t \in e.classes$$

$$\forall e : ENTITIES;\ i : INHERITANCE \bullet$$
$$i \in e.inheritance \Rightarrow \exists c_p, c_c : CLASS \bullet$$
$$c_p \in e.classes \land c_c \in e.classes \land c_p = i.parent \land c_c = i.child$$

$$\forall e : ENTITIES;\ i_1, i_2 : INHERITANCE \bullet$$
$$i_1 \in e.inheritance \land i_2 \in e.inheritance \land i_1.child = i_2.child$$
$$\land\ i_1.parent = i_2.parent \Rightarrow i_1 = i_2$$

$$\forall e : ENTITIES;\ c : CLASS \bullet$$
$$c \in e.classes \Rightarrow isInheritanceCyclical(c, e) = False$$

section *DatabaseModel* parents *Types*

$[DTYPE]$

$[VALUE]$

$CONSTRAINT ::= NOTNULL \mid UNIQUE$

COLUMN

$constraints : \mathbb{P}\ CONSTRAINT$
$type : DTYPE$
$label : LABEL$

COLUMNVALUE

$definition : COLUMN$
$value : VALUE$

PRIMARYKEY

$name : LABEL$

$$
\begin{schema}{PRIMARYKEYVALUE}
definition : PRIMARYKEY \\
value : \mathbb{Z}
\end{schema}
$$

$$
\begin{schema}{TABLESCHEMA}
label : LABEL \\
primKey : PRIMARYKEY \\
columns : \mathbb{P}\, COLUMN
\end{schema}
$$

$$
\begin{schema}{FOREIGNKEY}
label : LABEL \\
constraints : \mathbb{P}\, CONSTRAINT \\
source : TABLESCHEMA \\
reference : TABLESCHEMA
\end{schema}
$$

$$
\begin{schema}{FOREIGNKEYVALUE}
definition : FOREIGNKEY \\
value : \mathbb{Z}
\end{schema}
$$

$$
\begin{schema}{DATAVALUES}
definition : TABLESCHEMA \\
key : PRIMARYKEYVALUE \\
colValues : \mathbb{P}\, COLUMNVALUE \\
foreignkeyValues : \mathbb{P}\, FOREIGNKEYVALUE
\end{schema}
$$

$$
NULLDATAVALUE : DATAVALUES
$$

$$
\begin{schema}{SEQUENCE}
current : \mathbb{Z}
\end{schema}
$$

$$
\begin{schema}{DATABASE}
schemas : \mathbb{P}\, TABLESCHEMA \\
foreignKeys : \mathbb{P}\, FOREIGNKEY \\
values : \mathbb{P}\, DATAVALUES \\
sequence : SEQUENCE
\end{schema}
$$

$$
ERRDATABASE : DATABASE
$$

section *DatabaseInvariants* parents *DatabaseModel*

$$\forall ts_1, ts_2 : TABLESCHEMA;\ d : DATABASE \bullet$$
$$ts_1.label = ts_2.label \land ts_1 \in d.schemas \land ts_2 \in d.schemas \Rightarrow \quad ts_1 = ts_2$$

$$\forall col_1, col_2 : COLUMN;\ ts : TABLESCHEMA \bullet$$
$$col_1.label = col_2.label \land col_1 \in ts.columns \land col_2 \in ts.columns \Rightarrow col_1 = col_2$$

$$\forall fk_1, fk_2 : FOREIGNKEY;\ d : DATABASE \bullet$$
$$fk_1.label = fk_2.label \land fk_1 \in d.foreignKeys \land fk_2 \in d.foreignKeys \Rightarrow fk_1 = fk_2$$

$$\forall cv_1, cv_2 : COLUMNVALUE;\ cd : COLUMN \bullet$$
$$cv_1 \neq cv_2 \land cv_1.definition = cd \land cv_2.definition = cd \land$$
$$UNIQUE \in cd.constraints \Rightarrow cv_1.value \neq cv_2.value$$

$$\forall d : DATABASE;\ ts : TABLESCHEMA;\ col : COLUMN;\ td : DATAVALUES \bullet$$
$$ts \in d.schemas \land$$
$$col \in ts.columns \land$$
$$td.definition = ts \land$$
$$td \in d.values \land$$
$$NOTNULL \in col.constraints \Rightarrow$$
$$\exists cv : COLUMNVALUE \bullet cv \in td.colValues$$

$$\forall d : DATABASE;\ fk : FOREIGNKEY \bullet$$
$$fk \in d.foreignKeys \Leftrightarrow$$
$$\exists ds_s, ds_t : TABLESCHEMA \bullet$$
$$ds_s = fk.source \land$$
$$ds_t = fk.reference \land$$
$$ds_s \in d.schemas \land$$
$$ds_t \in d.schemas$$

$$\forall fv : FOREIGNKEYVALUE;\ d : DATABASE;\ dv : DATAVALUES \bullet$$
$$fv \in dv.foreignkeyValues \land dv \in d.values \Rightarrow$$
$$\exists dv_2 : DATAVALUES \bullet$$
$$dv_2.key.value = fv.value \land dv_2.definition = fv.definition.reference$$

$$\forall d : DATABASE;\ dv : DATAVALUES;\ cv : COLUMNVALUE;$$
$$fk : FOREIGNKEYVALUE \bullet$$
$$(dv \in d.values \Leftrightarrow dv.definition \in d.schemas) \land$$
$$(cv \in dv.colValues \Leftrightarrow cv.definition \in dv.definition.columns) \land$$
$$(fk \in dv.foreignkeyValues \Leftrightarrow fk.definition \in d.foreignKeys)$$

$$\forall\, dv_1, dv_2 : DATAVALUES;\ d : DATABASE \bullet$$
$$dv_1 \in d.values \land dv_2 \in d.values \land dv_1.key = dv_2.key \land$$
$$dv_1.definition = dv_2.definition \Rightarrow dv_1 = dv_2$$

section *Mapping* parents *DatabaseModel*

MAPPINGPAIR

$$source : DATAVALUES$$
$$target : DATAVALUES$$
$$source \neq NULLDATAVALUE$$

MAPPING

$$pairs : \mathbb{P}\, MAPPINGPAIR$$
$$\forall\, p_1, p_2 : MAPPINGPAIR \bullet$$
$$p_1.source.definition = p_2.source.definition \land$$
$$p_2.target.definition = p_1.target.definition$$

$$inverse : MAPPING \rightarrow MAPPING$$
$$\forall\, m, m^i : MAPPING \bullet$$
$$inverse(m) = m^i \Leftrightarrow$$
$$(\forall\, p : MAPPINGPAIR \bullet p \in m.pairs \Rightarrow$$
$$\exists\, p^i : MAPPINGPAIR \bullet$$
$$p^i \in m^i.pairs \land p.source = p^i.target \land p.target = p^i.source) \land$$
$$(\forall\, p^i : MAPPINGPAIR \bullet p^i \in m^i.pairs \Rightarrow$$
$$\exists\, p : MAPPINGPAIR \bullet$$
$$p \in m.pairs \land p.source = p^i.target \land p.target = p^i.source)$$

$$\forall\, d : DATABASE;\ m : MAPPING;\ p : MAPPINGPAIR \bullet$$
$$p \in m.pairs \Rightarrow p.source.definition \in d.schemas$$

$$\forall\, m : MAPPING;\ p_1, p_2 : MAPPINGPAIR;\ x_1, x_2, y_1, y_2 : DATAVALUES;$$
$$c_1, c_2 : COLUMNVALUE \bullet$$
$$p_1 \in m.pairs \land p_2 \in m.pairs \land x_1 = p_1.source \land$$
$$x_1 = p_1.source \land x_2 = p_2.source \land$$
$$y_1 = p_1.target \land y_2 = p_2.target \land c_1 \in y_1.colValues \land$$
$$c_2 \in y_2.colValues \land c_1.definition = c_2.definition \land$$
$$NOTNULL \in c_1.definition.constraints \Rightarrow c_1.value \neq c_2.value$$

$$
\begin{array}{|l}
\hline
\forall\, m : MAPPING;\ p : MAPPINGPAIR;\ c : COLUMN \bullet \\
\quad (p \in m.pairs \land c \in p.source.definition.columns \land NOTNULL \in c.constraints \Rightarrow \\
\qquad \exists\, cv : COLUMNVALUE \bullet cv \in p.source.colValues \land cv.definition = c) \lor \\
\quad (c \in p.target.definition.columns \land NOTNULL \in c.constraints \Rightarrow \\
\qquad \exists\, cv : COLUMNVALUE \bullet cv \in p.target.colValues \land cv.definition = c) \\
\forall\, m : MAPPING;\ p : MAPPINGPAIR;\ f : FOREIGNKEY \bullet \\
\quad (p \in m.pairs \land f.source = p.source.definition \land NOTNULL \in f.constraints \Rightarrow \\
\qquad \exists\, fv : FOREIGNKEYVALUE \bullet fv \in p.source.foreignkeyValues \land \\
\qquad fv.definition = f) \lor \\
\quad (p \in m.pairs \land f.source = p.target.definition \land NOTNULL \in f.constraints \Rightarrow \\
\qquad \exists\, fv : FOREIGNKEYVALUE \bullet fv \in p.target.foreignkeyValues \land \\
\qquad fv.definition = f) \\
\hline
\end{array}
$$

MappingSourceComplete

$$
\begin{array}{|l}
\hline
\Xi DATABASE \\
map? : MAPPING \\
m : MAPPINGPAIR \\
\hline
m \in map?.pairs \\
\forall\, ds : DATAVALUES \bullet \\
\quad ds \in values \land ds.definition = m.source.definition \Leftrightarrow \\
\quad \exists\, mp : MAPPINGPAIR \bullet mp.source = ds \land mp \in map?.pairs \\
\hline
\end{array}
$$

MappingTargetComplete

$$
\begin{array}{|l}
\hline
\Xi DATABASE \\
map? : MAPPING \\
m : MAPPINGPAIR \\
\hline
m \in map?.pairs \\
\forall\, ds : DATAVALUES \bullet \\
\quad ds \in values \land ds.definition = m.target.definition \Leftrightarrow \\
\quad \exists\, mp : MAPPINGPAIR \bullet mp.target = ds \land mp \in map?.pairs \\
\hline
\end{array}
$$

MappingFullComplete

$$
\begin{array}{|l}
\hline
\Xi DATABASE \\
map? : MAPPING \\
m : MAPPINGPAIR \\
\hline
MappingSourceComplete \\
MappingTargetComplete \\
\hline
\end{array}
$$

MappingIsSimple

$$\Xi DATABASE$$
$$map? : MAPPING$$
$$m? : MAPPING$$

$$\forall dvs, dvt : DATAVALUES;\ m, m_2 : MAPPINGPAIR \bullet$$
$$dvs \in values \land dvt \in values \land m \in map?.pairs \land m_2 \in map?.pairs \Rightarrow$$
$$(dvs = m.source \land dvs = m_2.source \Rightarrow m = m_2) \land$$
$$(dvt = m.target \land dvt = m_2.target \Rightarrow m = m_2)$$

MappinNoTargetDuplicates

$$\Xi DATABASE$$
$$map? : MAPPING$$

$$\exists dvs : DATAVALUES;\ m, m_2 : MAPPINGPAIR \bullet$$
$$dvs \in values \land m \in map?.pairs \land m_2 \in map?.pairs \land$$
$$dvs = m.source \land dvs = m_2.source \land m \neq m_2$$
$$\forall dvt : DATAVALUES;\ m, m_2 : MAPPINGPAIR \bullet$$
$$dvt \in values \land dvt \in values \land m \in map?.pairs \land m_2 \in map?.pairs \land$$
$$dvt = m.target \land dvt = m_2.target \Rightarrow m = m_2$$

MappinNoSourceDuplicates

$$\Xi DATABASE$$
$$map? : MAPPING$$

$$\exists dvt : DATAVALUES;\ m, m_2 : MAPPINGPAIR \bullet$$
$$dvt \in values \land m \in map?.pairs \land m_2 \in map?.pairs \land$$
$$dvt = m.target \land dvt = m_2.target \land m \neq m_2$$
$$\forall dvs : DATAVALUES;\ m, m_2 : MAPPINGPAIR \bullet$$
$$dvs \in values \land m \in map?.pairs \land$$
$$dvs = m.source \land dvs = m_2.source \Rightarrow m = m_2$$

MappinWithDuplicates

$$\Xi DATABASE$$
$$map? : MAPPING$$

$$\exists dvt : DATAVALUES;\ m, m_2 : MAPPINGPAIR \bullet$$
$$dvt \in values \land m \in map?.pairs \land m_2 \in map?.pairs \land$$
$$dvt = m.target \land dvt = m_2.target \land m \neq m_2$$
$$\exists dvs : DATAVALUES;\ m, m_2 : MAPPINGPAIR \bullet$$
$$dvs \in values \land m \in map?.pairs \land m_2 \in map?.pairs \land$$
$$dvs = m.source \land dvs = m_2.source \land m \neq m_2$$

section *DatabaseHelpers* parents *Mapping*

insertDataToFKDB

$\Delta DATABASE$
$fk? : FOREIGNKEY$
$map? : MAPPING$

$\forall\, dv, dv' : DATAVALUES;\ p : MAPPINGPAIR;$
$\quad fkv : FOREIGNKEYVALUE \bullet p \in map?.pairs \land dv = p.target \land$
$\qquad fkv.value = p.source.key.value \land fkv.definition = fk? \Rightarrow$
$\qquad dv'.foreignkeyValues = dv.foreignkeyValues \cup \{fkv\}$

insertDataToMapTableDB

$\Delta DATABASE$
$ts? : TABLESCHEMA$
$map? : MAPPING$

$\forall\, dv1, dv2, dv' : DATAVALUES;\ p : MAPPINGPAIR;$
$\quad fkv, fkv2 : FOREIGNKEYVALUE;\ fk, fk2 : FOREIGNKEY \bullet$
$\quad p \in map?.pairs \land dv1 = p.target \land dv2 = p.source \land fk.source = ts? \land$
$\quad fk.reference = dv1.definition \land fk2.source = ts? \land$
$\quad fk2.reference = dv2.definition \land fkv.definition = fk \land$
$\quad fkv2.definition = fk2 \Rightarrow$
$\quad fkv.value = dv1.key.value \land fkv2.value = dv2.key.value$

initDatabase

$d? : DATABASE$

$d?.schemas = \varnothing$
$d?.foreignKeys = \varnothing$
$d?.values = \varnothing$
$d?.sequence.current = 0$

initColumn

$col! : COLUMN$
$constraints? : \mathbb{P}\, CONSTRAINT$
$l? : LABEL$

$col!.label = l?$
$col!.type \in DTYPE$
$col!.constraints = constraints?$

initTableSchema

$ts! : TABLESCHEMA$
$label? : LABEL$
$primKey? : PRIMARYKEY$
$columns? : \mathbb{P}\, COLUMN$

$ts!.label = label?$
$ts!.primKey = primKey?$
$ts!.columns = columns?$

initPrimaryKey

$primKey! : PRIMARYKEY$
$l? : LABEL$

$primKey!.name = l?$

initForeignKey

$l? : LABEL$
$constraints? : \mathbb{P}\, CONSTRAINT$
$source? : TABLESCHEMA$
$reference? : TABLESCHEMA$
$fk! : FOREIGNKEY$

$fk!.label = l?$
$fk!.constraints = constraints?$
$fk!.source = source?$
$fk!.reference = reference?$

$valueOfColumn : COLUMN \times DATAVALUES \to \mathbb{P}\, COLUMNVALUE$

$\forall\, c : COLUMN;\ d : DATAVALUES \bullet$
$valueOfColumn(c, d) =$
$\{cv : COLUMNVALUE \mid cv.definition = c \land cv \in d.colValues\}$

$referingSchemas : TABLESCHEMA \times DATABASE \to \mathbb{P}\, FOREIGNKEY$

$\forall\, ts : TABLESCHEMA;\ d : DATABASE;\ fks : \mathbb{P}\, FOREIGNKEY \bullet$
$referingSchemas(ts, d) =$
$\{fk : FOREIGNKEY \mid fk \in d.foreignKeys \land fk.reference = ts\}$

$selectAllData : TABLESCHEMA \times DATABASE \to \mathbb{P}\, DATAVALUES$

$\forall\, ts : TABLESCHEMA;\ d : DATABASE \bullet ts \in d.schemas \Rightarrow$
$selectAllData(ts, d) = \{dv : DATAVALUES \mid$
$dv \in d.values \land dv.definition = ts\}$

addTableDB

$$\Delta DATABASE$$
$$ts? : TABLESCHEMA$$

$$\forall ts : TABLESCHEMA \bullet$$
$$\quad ts \in schemas \land ts.label \neq ts?.label$$
$$schemas' = schemas \cup \{ts?\}$$

dropTableDB

$$\Delta DATABASE$$
$$ts? : TABLESCHEMA$$

$$ts? \in schemas$$
$$referingSchemas(ts?, \theta DATABASE) = \varnothing$$
$$schemas' = schemas \setminus \{ts?\}$$
$$values' = values \setminus \{val : DATAVALUES \mid$$
$$\quad val \in values \land val.definition = ts?\}$$

dropEmptyTableDB

$$\Delta DATABASE$$
$$ts? : TABLESCHEMA$$

$$\{d : DATAVALUES \mid d \in values \land d.definition = ts?\} = \varnothing$$
$$dropTableDB$$

addColumnDB

$$\Delta DATABASE$$
$$\Delta TABLESCHEMA$$
$$col? : COLUMN$$

$$\forall col : COLUMN \bullet$$
$$\quad col \in columns \Rightarrow col.label \neq col?.label$$
$$columns' = columns \cup \{col?\}$$

dropColumnDB

$$
\begin{array}{l}
\Delta DATABASE \\
\Delta TABLESCHEMA \\
col? : COLUMN \\
\hline
col? \in columns \\
columns' = columns \setminus \{col?\} \\
\forall\, dv, dv' : DATAVALUES;\ cv : COLUMNVALUE \bullet \\
\quad dv.definition = \theta TABLESCHEMA \land cv.definition = col? \land \\
\quad cv \in dv.colValues \Rightarrow \\
\qquad dv'.definition = dv.definition \land dv'.key = dv.key \land \\
\qquad dv'.foreignkeyValues = dv.foreignkeyValues \land \\
\qquad dv'.colValues = dv.colValues \setminus \{cv\} \land \\
\qquad values' = (values \setminus \{dv\}) \cup \{dv'\}
\end{array}
$$

dropEmptyColumnDB

$$
\begin{array}{l}
\Delta DATABASE \\
\Delta TABLESCHEMA \\
col? : COLUMN \\
\hline
\{cv : COLUMNVALUE \mid cv.definition = col?\} = \varnothing \\
dropColumnDB
\end{array}
$$

addForeignKeyDB

$$
\begin{array}{l}
\Delta DATABASE \\
fk? : FOREIGNKEY \\
\hline
fk?.source \in schemas \\
fk?.reference \in schemas \\
NOTNULL \in fk?.constraints \Leftrightarrow \\
\{dv : DATAVALUES \mid dv.definition = fk?.source\} = \varnothing \\
foreignKeys' = foreignKeys \cup \{fk?\}
\end{array}
$$

dropForeignKeyDB

$$
\begin{array}{l}
\Delta DATABASE \\
fk? : FOREIGNKEY \\
\hline
fk? \in foreignKeys \\
\forall\, dv, dv' : DATAVALUES;\ fv : FOREIGNKEYVALUE \bullet \\
\quad dv.definition = fk?.source \land fv.definition = fk? \land \\
\quad fv \in dv.foreignkeyValues \Rightarrow \\
\qquad dv'.definition = dv.definition \land dv'.key = dv.key \land \\
\qquad dv'.colValues = dv.colValues \land \\
\qquad dv'.foreignkeyValues = dv.foreignkeyValues \setminus \{fv\} \land \\
\qquad values' = (values \setminus \{dv\}) \cup \{dv'\} \\
foreignKeys' = foreignKeys \setminus \{fk?\}
\end{array}
$$

dropEmptyForeignKeyDB

$\Delta DATABASE$
$fk? : FOREIGNKEY$

$\{fkv : FOREIGNKEYVALUE \mid fkv.definition = fk?\} = \varnothing$
$dropForeignKeyDB$

copyColumnDB

$\Delta DATABASE$
$\Delta TABLESCHEMA$
$col? : COLUMN$
$sourceSchema? : TABLESCHEMA$
$targetSchema? : TABLESCHEMA$
$map? : MAPPING$
$targetSchema' : TABLESCHEMA$

$targetSchema? = \theta TABLESCHEMA$
$targetSchema' = \theta(TABLESCHEMA)'$
$col? \in sourceSchema?.columns$
$sourceSchema? \in schemas$
$targetSchema? \in schemas$
$targetSchema'.columns = targetSchema?.columns \cup \{col?\}$
$\forall\, m : MAPPINGPAIR;\ cval, dval : DATAVALUES;$
$\quad colval : COLUMNVALUE \bullet$
$\quad\quad m.source.definition = sourceSchema? \land m.target.definition = targetSchema? \land$
$\quad\quad cval = m.source \land dval = m.target \land colval.definition = col? \Rightarrow$
$\quad\quad values' = values \setminus \{dval\} \cup \{dval' : DATAVALUES \mid$
$\quad\quad\quad dval'.colValues = dval.colValues \cup \{colval\} \land$
$\quad\quad\quad dval'.key = dval.key \land dval'.definition = dval.definition \land$
$\quad\quad\quad dval'.foreignkeyValues = dval.foreignkeyValues\}$

copyTableStructureDB

$\Delta DATABASE$
$ts? : TABLESCHEMA$
$l? : LABEL$
$ts : TABLESCHEMA$

$ts? \in schemas$
$\forall\, t : TABLESCHEMA \bullet$
$\quad t \in schemas \Rightarrow t.label \neq l?$
$ts.label = l?$
$ts.columns = ts?.columns$
$ts.primKey = ts?.primKey$
$schemas' = schemas \cup \{ts\}$
$\forall\, fk : FOREIGNKEY \bullet$
$\quad fk \in foreignKeys \land fk.source = ts? \Rightarrow$
$\quad foreignKeys' = foreignKeys \cup \{fk' : FOREIGNKEY \mid$
$\qquad fk'.source = ts \land fk'.reference = fk.reference \land$
$\quad fk'.constraints = fk.constraints \land fk'.label = fk.label\}$

copyTableDB

$\Delta DATABASE$
$ts? : TABLESCHEMA$
$l? : LABEL$
$ts : TABLESCHEMA$

$copyTableStructureDB \land$
$\forall\, dv : DATAVALUES \bullet$
$\quad dv \in values \land dv.definition = ts? \Rightarrow$
$\quad values' = values \cup \{dv' : DATAVALUES \mid$
$\qquad dv'.definition = dv.definition \land dv'.colValues = dv.colValues \land$
$\qquad dv'.key = dv'.key \land dv'.foreignkeyValues = dv.foreignkeyValues\}$

$next : SEQUENCE \to \mathbb{Z}$

section *ORM* parents *ApplicationHelpers*, *DatabaseHelpers*

$dbNameORM : LABEL \to LABEL$

attributeToColumnORM

$p? : ATTRIBUTE$
$col! : COLUMN$

$col!.label = dbNameORM(p?.label)$
$col!.type \in DTYPE$
$p?.optional = True \Rightarrow NOTNULL \in col!.constraints$

attributeToTableORM

$\Xi DATABASE$
$p? : ATTRIBUTE$
$ts! : TABLESCHEMA$
$label : LABEL$
$primKey : PRIMARYKEY$
$constraints : \mathbb{P}\, CONSTRAINT$
$col : COLUMN$
$columns : \mathbb{P}\, COLUMN$

$label = dbNameORM(p?.label)$
$initPrimaryKey[label/l?, primKey/primKey!]$
$p?.optional = True \Rightarrow constraints = \{NOTNULL\}$
$p?.optional = False \Rightarrow constraints = \varnothing$
$initColumn[col/col!, constraints/constraints?, label/l?]$
$columns = \{col\}$
$initTableSchema[label/label?, primKey/primKey?, columns/columns?]$

attributesToDbORM

$\Xi DATABASE$
$columns! : \mathbb{P}\, COLUMN$
$tables! : \mathbb{P}\, TABLESCHEMA$
$attributes? : \mathbb{P}\, ATTRIBUTE$
$col : COLUMN$
$ts : TABLESCHEMA$
$l, label : LABEL$
$primKey : PRIMARYKEY$
$constraints : \mathbb{P}\, CONSTRAINT$
$columns : \mathbb{P}\, COLUMN$

$\forall\, p : ATTRIBUTE \bullet (p \in attributes? \land p.upper = One \Rightarrow$
$\quad attributeToColumnORM[p/p?, col/col!] \land col \in columns!) \lor$
$(p \in attributes? \land p.upper = Many \Rightarrow attributeToTableORM[p/p?, ts/ts!] \land$
$ts \in tables!)$

entityOutsideHierarchyToTableORM

$\Xi ENTITIES$
$c? : CLASS$
$ts! : TABLESCHEMA$
$label : LABEL$
$atts : \mathbb{P}\, ATTRIBUTE$
$primKey : PRIMARYKEY$
$schemas, schemas' , tables : \mathbb{P}\, TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY$
$values, values' : \mathbb{P}\, DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\, COLUMN$
$col : COLUMN$
$ts, ts! : TABLESCHEMA$
$l : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$

$(parentOf(c?, \theta(ENTITIES)) = NULLCLASS \land$
$children(c?, \theta(ENTITIES)) = \varnothing) \Rightarrow$
$\quad label = dbNameORM(c?.label) \land$
$\quad atts = attributesOf(c?, \theta(ENTITIES)) \land$
$\quad initPrimaryKey[label/l?, primKey/primKey!] \land$
$\quad attributesToDbORM[columns/columns!, attributes/attributes?, tables/tables!] \land$
$\quad initTableSchema[label/label?, primKey/primKey?, columns/columns?]$

$INSTANCEDEF : LABEL$

parentEntityToTableORM

$\Xi ENTITIES$
$c? : CLASS$
$ts! : TABLESCHEMA$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\, ATTRIBUTE$
$schemas, schemas' , tables : \mathbb{P}\, TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY$
$values, values' : \mathbb{P}\, DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\, COLUMN$
$col, col2 : COLUMN$
$ts : TABLESCHEMA$
$l : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$
$type : DTYPE$

$parentOf(c?, \theta(ENTITIES)) = NULLCLASS$
$children(c?, \theta(ENTITIES)) \neq \varnothing$
$classes = \{c : CLASS \mid c \in \mathrm{dom}(childParentRelation(c?, \theta(ENTITIES))^{+})\}$
$label = dbNameORM(c?.label)$
$initPrimaryKey[label/l?, primKey/primKey!]$
$\forall a : ATTRIBUTE \bullet$
$\quad a \in atts \Leftrightarrow \exists c : CLASS \bullet c \in classes \land a \in attributesOf(c, \theta(ENTITIES))$
$attributesToDbORM[columns/columns!, atts/attributes?, tables/tables!] \gg$
$[\mid constraints = \{NOTNULL\} \land$
$\quad initColumn[INSTANCEDEF/l?, constraints/constraints?, col2/col!] \land$
$\quad\quad columns \cup \{col2\}] \gg$
$initTableSchema[label/label?, primKey/primKey?, columns/columns?]$

entityToTableNoAttributesORM

$\Xi ENTITIES$
$c? : CLASS$
$ts! : TABLESCHEMA$
$label : LABEL$
$columns : \mathbb{P}\, COLUMN$
$primKey : PRIMARYKEY$

$label = dbNameORM(c?.label)$
$columns = \varnothing$
$initPrimaryKey[label/l?, primKey/primKey!]$
$initTableSchema[label/label?, primKey/primKey?, columns/columns?]$

entityToTableORM

$\Xi ENTITIES$
$c? : CLASS$
$ts! : TABLESCHEMA$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\ ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\ TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\ FOREIGNKEY$
$values, values' : \mathbb{P}\ DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\ COLUMN$
$col, col2 : COLUMN$
$ts, ts! : TABLESCHEMA$
$l : LABEL$
$type : DTYPE$
$constraints : \mathbb{P}\ CONSTRAINT$

$parentEntityToTableORM \lor$
$entityOutsideHierarchyToTableORM$

assocToFkORM

$\Xi ENTITIES$
$\Xi DATABASE$
$a? : ASSOCIATION$
$fk! : FOREIGNKEY$
$name : LABEL$
$c, d : CLASS$
$sourceSchema, targetSchema : TABLESCHEMA$
$constraints : \mathbb{P}\ CONSTRAINT$
$l, label : LABEL$
$primKey : PRIMARYKEY$
$columns : \mathbb{P}\ COLUMN$
$tables : \mathbb{P}\ TABLESCHEMA$
$col : COLUMN$
$ts : TABLESCHEMA$
$atts : \mathbb{P}\ ATTRIBUTE$
$col2 : COLUMN$
$type : DTYPE$

$name = dbNameORM(a?.label)$
$a?.optional = True \Rightarrow constraints = \{NOTNULL\}$
$a?.optional = False \Rightarrow constraints = \varnothing$
$c = a?.source$
$entityToTableORM[c/c?, sourceSchema/ts!]$
$d = a?.target$
$entityToTableORM[d/c?, targetSchema/ts!]$
$initForeignKey[name/l?, constraints/constraints?, sourceSchema/source?,$
$\quad targetSchema/reference?]$

assocToTableORM

$\Xi DATABASE$
$\Xi ENTITIES$
$a? : ASSOCIATION$
$ts! : TABLESCHEMA$
$fk1, fk2 : FOREIGNKEY$
$l : LABEL$
$primKey : PRIMARYKEY$
$constraints : \mathbb{P}\, CONSTRAINT$
$columns : \mathbb{P}\, COLUMN$
$sourceCLASS, targetCLASS : CLASS$
$sourceSchema, targetSchema : TABLESCHEMA$
$label : LABEL$
$ts, table : TABLESCHEMA$
$tables : \mathbb{P}\, TABLESCHEMA$
$col : COLUMN$
$atts : \mathbb{P}\, ATTRIBUTE$
$col2 : COLUMN$
$type : DTYPE$

$l = dbNameORM(a?.label)$
$initPrimaryKey[l/l?, primKey/primKey!]$
$a?.optional = True \Rightarrow constraints = \{NOTNULL\}$
$a?.optional = False \Rightarrow constraints = \varnothing$
$columns = \varnothing$
$initTableSchema[l/label?, primKey/primKey?,$
$columns/columns?, table/ts!]$
$sourceCLASS = a?.source$
$targetCLASS = a?.target$
$entityToTableORM[sourceCLASS/c?, sourceSchema/ts!]$
$entityToTableORM[targetCLASS/c?, targetSchema/ts!]$
$initForeignKey[table/source?, sourceSchema/reference?,$
$\quad constraints/constraints?, label/l?, fk1/fk!]$
$initForeignKey[table/source?, targetSchema/reference?,$
$\quad constraints/constraints?, label/l?, fk2/fk!]$

ORM

$\Xi ENTITIES$
$\Xi DATABASE$
$e? : ENTITIES$
$d? : DATABASE$
$label, l, name : LABEL$
$primKey : PRIMARYKEY$
$columns : \mathbb{P}\ COLUMN$
$tables : \mathbb{P}\ TABLESCHEMA$
$col : COLUMN$
$sourceSchema, targetSchema, table, ts : TABLESCHEMA$
$constraints : \mathbb{P}\ CONSTRAINT$
$c, d, sourceCLASS, targetCLASS : CLASS$
$fk1, fk2 : FOREIGNKEY$
$atts : \mathbb{P}\ ATTRIBUTE$
$col2 : COLUMN$
$type : DTYPE$

$\forall\, c : CLASS \bullet$
$\quad c \in e?.classes \Leftrightarrow$
$\quad \exists\, td, td2 : TABLESCHEMA \bullet$
$\quad\quad td \in d?.schemas \land entityToTableORM[c/c?, td2/ts!] \land td2 = td$
$\forall\, a : ASSOCIATION \bullet$
$\quad a \in e?.associations \land a.upper = Many \Leftrightarrow$
$\quad \exists\, fk, fk2 : FOREIGNKEY \bullet$
$\quad\quad fk \in d?.foreignKeys \land assocToFkORM[a/a?, fk2/fk!] \land fk2 = fk$
$\forall\, a : ASSOCIATION \bullet$
$\quad a \in e?.associations \land a.upper = One \Leftrightarrow$
$\quad \exists\, td, td2 : TABLESCHEMA \bullet$
$\quad\quad td \in d?.schemas \land assocToTableORM[a/a?, td2/ts!] \land td2 = td$

section *Software* parents *DatabaseModel*, *ApplicationModel*, *ORM*

SOFTWARE

$entities : ENTITIES$
$database : DATABASE$

$\Xi SOFTWARE$
$\Xi ENTITIES$
$\Xi ENTITIES$
$\Xi DATABASE$
$label, l, name : LABEL$
$primKey : PRIMARYKEY$
$columns : \mathbb{P}\, COLUMN$
$tables : \mathbb{P}\, TABLESCHEMA$
$col : COLUMN$
$sourceSchema, targetSchema, table, ts : TABLESCHEMA$
$constraints : \mathbb{P}\, CONSTRAINT$
$c, d, sourceCLASS, targetCLASS : CLASS$
$fk1, fk2 : FOREIGNKEY$
$atts : \mathbb{P}\, ATTRIBUTE$
$col2 : COLUMN$
$type : DTYPE$

$\forall\, s : SOFTWARE;\ entities : ENTITIES;\ database : DATABASE \bullet$
$entities = s.entities \land database = s.database \land$
$entities \neq ERRENTITIES \land$
$database \neq ERRDATABASE \land$
$ORM[entities/e?, database/d?]$

initSoftware

$SOFTWARE$

$initDatabase[database/d?]$
$initEntities[entities/e?]$

section *RefactoringHelpers* parents *Software*, *DatabaseHelpers*, *ApplicationHelpers*

moveAttributes

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$c? : CLASS$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\ ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\ TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\ FOREIGNKEY$
$values, values' : \mathbb{P}\ DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\ COLUMN$
$col : COLUMN$
$pts, ts, ts! : TABLESCHEMA$
$l : LABEL$
$constraints : \mathbb{P}\ CONSTRAINT$
$d : CLASS$
$col2 : COLUMN$
$type : DTYPE$

$d = parentOf(c?, entities)$
$entityToTableORM[d/c?, pts/ts!]$
$\forall p : MAPPINGPAIR \bullet$
$\quad p \in map.pairs \Leftrightarrow p.source = p.target \land p.source.definition = pts$
$\forall p : ATTRIBUTE \bullet$
$\quad p \in attributesOf(c?, entities) \Rightarrow moveAttribute[d/d?, p/p?, map/map?]$

changeAssociationDirectionEL

$\Delta ASSOCIATION$
$target? : CLASS$
$a? : ASSOCIATION$

$a? = \theta(ASSOCIATION)$
$target' = target?$

changeFKreferenceDB

$\Delta DATABASE$
$fk? : FOREIGNKEY$
$targetSchema? : TABLESCHEMA$
$map? : MAPPING$
$fk : FOREIGNKEY$

$fk.label = fk?.label$
$fk.constraints = fk?.constraints$
$fk.source = fk?.source$
$fk.reference = targetSchema?$
$foreignKeys' = foreignKeys \setminus \{fk?\} \cup \{fk\}$
$\forall\, dv, dv' : DATAVALUES;\ fkv, fkv' : FOREIGNKEYVALUE;$
$\quad p : MAPPINGPAIR \bullet$
$\quad dv.definition = fk.source \land$
$\quad fkv.definition = fk \land$
$\quad fkv \in dv.foreignkeyValues \land dv = p.source \Rightarrow$
$\quad fkv'.definition = fk? \land$
$\quad fkv'.value = p.target.key.value \land$
$\quad dv'.foreignkeyValues = dv.foreignkeyValues \setminus \{fkv\} \cup \{fkv'\}$

changeReferenceTableDB

$\Xi ENTITIES$
$\Delta DATABASE$
$ts? : TABLESCHEMA$
$newTarget?, oldTarget? : CLASS$
$map? : MAPPING$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\, ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\, TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY$
$values, values' : \mathbb{P}\, DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\, COLUMN$
$col : COLUMN$
$tso, ts, ts! : TABLESCHEMA$
$l : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$
$fk : FOREIGNKEY$
$col2 : COLUMN$
$type : DTYPE$

$entityToTableORM[newTarget?/c?, ts/ts!]$
$entityToTableORM[oldTarget?/c?, tso/ts!]$
$\forall fk : FOREIGNKEY \bullet$
  $fk.source = ts? \land fk.reference = tso$
$changeFKreferenceDB[fk/fk?, ts/targetSchema?]$

changeReferenceInDB

$\Xi ENTITIES$
$\Delta DATABASE$
$a? : ASSOCIATION$
$target? : CLASS$
$map? : MAPPING$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\, ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\, TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY$
$values, values' : \mathbb{P}\, DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\, COLUMN$
$col : COLUMN$
$tso, ts, ts!, targetSchema, sourceSchema, table : TABLESCHEMA$
$l, name : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$
$fk, fk1, fk2 : FOREIGNKEY$
$c, d, sourceCLASS, targetCLASS : CLASS$
$col2 : COLUMN$
$type : DTYPE$

$entityToTableORM[target?/c?, targetSchema/ts!]$
$a?.upper = One \Rightarrow assocToFkORM \gg$
  $changeFKreferenceDB[targetSchema/targetSchema?]$
$a?.upper = Many \Rightarrow \exists\, c == a?.source \bullet assocToTableORM \gg$
  $changeReferenceTableDB[target?/newTarget?, c/oldTarget?]$

initMappingForSplit

$\Xi ENTITIES$
$\Xi DATABASE$
$map! : MAPPING$
$old?, new? : CLASS$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\, ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\, TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY$
$values, values' : \mathbb{P}\, DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\, COLUMN$
$col : COLUMN$
$ts, ts!, oldSchema, newSchema : TABLESCHEMA$
$l : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$
$col2 : COLUMN$
$type : DTYPE$

$entityToTableORM[old?/c?, oldSchema/ts!]$
$entityToTableORM[old?/c?, newSchema/ts!]$
$\forall\, m : MAPPINGPAIR \bullet$
$\quad m \in map!.pairs \Rightarrow$
$\quad m.source \in selectAllData(oldSchema, \theta(DATABASE)) \Leftrightarrow$
$\quad m.target.definition = newSchema \land$
$\quad m.target.key = m.source.key \land$
$\quad \#m.target.colValues = 1 \land$
$\quad \forall\, cv : COLUMNVALUE;\ c : COLUMN \bullet$
$\quad\quad cv \in m.target.colValues \Rightarrow$
$\quad\quad cv.definition = c \land c \in newSchema.columns$

initMappingForRemoveParent

$\Xi ENTITIES$
$\Xi DATABASE$
$map? : MAPPING$
$cts? : TABLESCHEMA$
$c? : CLASS$
$name, l, label : LABEL$
$c, d : CLASS$
$ts, sourceSchema, targetSchema : TABLESCHEMA$
$constraints : \mathbb{P}\, CONSTRAINT$
$primKey : PRIMARYKEY$
$columns : \mathbb{P}\, COLUMN$
$tables : \mathbb{P}\, TABLESCHEMA$
$col : COLUMN$
$atts : \mathbb{P}\, ATTRIBUTE$

$\forall mp : MAPPINGPAIR;\ dv : DATAVALUES \bullet mp \in map?.pairs \Leftrightarrow mp.source.definition =$

initMappingForExtractParent

$\Xi ENTITIES$
$map! : MAPPING$
$parent?, child? : CLASS$
$tsc, tsp : TABLESCHEMA$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\, ATTRIBUTE$
$schemas, schemas' , tables : \mathbb{P}\, TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY$
$values, values' : \mathbb{P}\, DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\, COLUMN$
$col : COLUMN$
$ts, ts! : TABLESCHEMA$
$l : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$
$col2 : COLUMN$
$type : DTYPE$

$entityToTableORM[child?/c?, tsc/ts!]$
$entityToTableORM[parent?/c?, tsp/ts!]$
$\forall dvc : DATAVALUES;\ m : MAPPINGPAIR \bullet$
$\quad dvc.definition = tsc \land m \in map!.pairs \Leftrightarrow$
$\quad m.source = dvc \land \exists dvp : DATAVALUES \bullet dvp.key = dvc.key$
$\qquad \land\ dvp.definition = tsp \land m.target = dvp$

changeReferenceValueInForeignKeyValueDB

$\Delta DATABASE$
$old?, new? : FOREIGNKEY$
$fkv, fkv' : FOREIGNKEYVALUE$

$\forall\, dv, dv' : DATAVALUES;\ fkv : FOREIGNKEYVALUE \bullet$
$dv \in values \land fkv.definition = old? \Rightarrow$
$fkv'.definition = new? \land$
$fkv'.value = fkv.value \land$
$dv'.foreignkeyValues = dv.foreignkeyValues \setminus \{fkv\} \cup \{fkv'\} \land$
$values' = values \setminus \{dv\} \cup \{dv'\}$

changeForeignKeyReferenceDB

$\Delta DATABASE$
$newReference?, oldReference? : TABLESCHEMA$
$label : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$
$source : TABLESCHEMA$
$fk1, fk2 : FOREIGNKEY$
$fkv, fkv' : FOREIGNKEYVALUE$

$\forall\, ts : TABLESCHEMA;\ fk : FOREIGNKEY \bullet$
$ts \in schemas \land fk.source = ts \land$
$fk.reference = oldReference? \land$
$label = fk.label \land$
$constraints = fk.constraints \land$
$source = fk.source \land$
$initForeignKey[label/l?, constraints/constraints?, source/source?,$
$\quad newReference?/reference?, fk1/fk!] \gg$
$addForeignKeyDB[fk1/fk?] \gg$
$changeReferenceValueInForeignKeyValueDB[fk/old?, fk1/new?] \gg$
$dropForeignKeyDB[fk/fk?]$

changeAllReferencesInTable

$\Delta DATABASE$
$ts? : TABLESCHEMA$
$target? : TABLESCHEMA$
$map? : MAPPING$

$\forall\, fk : FOREIGNKEY \bullet$
$fk \in foreignKeys \land fk.source = ts? \Rightarrow$
$changeFKreferenceDB[fk/fk?, target?/targetSchema?]$

$$isInstanceOf : DATAVALUES \times CLASS \to BOOL$$

$$\begin{aligned}
&\forall\, dv : DATAVALUES;\ c : CLASS \bullet \\
&\quad (isInstanceOf(dv, c) = True \Leftrightarrow \exists\, cv : COLUMNVALUE \bullet \\
&\qquad cv.definition.label = INSTANCEDEF \land cv.value = c.label) \lor \\
&\quad (isInstanceOf(dv, c) = False \Leftrightarrow \forall\, cv : COLUMNVALUE \bullet \\
&\qquad cv.definition.label = INSTANCEDEF \land cv.value \neq c.label)
\end{aligned}$$

section *Refactorings* parents *RefactoringHelpers*

addAttribute

$$\begin{aligned}
&\Delta SOFTWARE \\
&\Delta ENTITIES \\
&\Delta DATABASE \\
&c? : CLASS \\
&p? : ATTRIBUTE \\
&label : LABEL \\
&primKey : PRIMARYKEY \\
&atts : \mathbb{P}\, ATTRIBUTE \\
&schemas, schemas', tables : \mathbb{P}\, TABLESCHEMA \\
&foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY \\
&values, values' : \mathbb{P}\, DATAVALUES \\
&sequence, sequence' : SEQUENCE \\
&columns, columns' : \mathbb{P}\, COLUMN \\
&col : COLUMN \\
&ts, ts! : TABLESCHEMA \\
&l, label' : LABEL \\
&constraints : \mathbb{P}\, CONSTRAINT \\
&poc : ATTRIBUTEOfCLASS \\
&primKey, primKey' : PRIMARYKEY \\
&col2 : COLUMN \\
&type : DTYPE
\end{aligned}$$

$$\begin{aligned}
&entityToTableORM[ts/ts!] \\
&p?.optional = True \Rightarrow selectAllData(ts, \theta(DATABASE)) \neq \varnothing \\
&addAttributeEL \\
&(p?.upper = One \Rightarrow attributeToColumnORM \gg addColumnDB) \\
&(p?.upper = Many \Rightarrow attributeToTableORM \gg addTableDB)
\end{aligned}$$

addAssociation

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$a? : ASSOCIATION$
$c? : CLASS$
$map? : MAPPING$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\ ATTRIBUTE$
$schemas, schemas' , tables : \mathbb{P}\ TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\ FOREIGNKEY$
$values, values' : \mathbb{P}\ DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\ COLUMN$
$col : COLUMN$
$ts, sourceSchema, targetSchema, table : TABLESCHEMA$
$l, name : LABEL$
$constraints : \mathbb{P}\ CONSTRAINT$
$c, d, sourceCLASS, targetCLASS : CLASS$
$fk1, fk2 : FOREIGNKEY$
$col2 : COLUMN$
$type : DTYPE$

$entityToTableORM[ts/ts!]$
$a?.optional = True \Rightarrow selectAllData(ts, \theta(DATABASE)) \neq \varnothing$
$addAssociationEL \gg$
$[|\ a?.upper = One \Rightarrow assocToFkORM \gg (addForeignKeyDB \gg insertDataToFKDB) \vee$
$a?.upper = Many \Rightarrow assocToTableORM \gg (addTableDB \gg insertDataToMapTableDB)]$

addClass

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$c? : CLASS$
$att? : \mathbb{P}\, ATTRIBUTE$
$label, label' : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\, ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\, TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY$
$values, values' : \mathbb{P}\, DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\, COLUMN$
$col : COLUMN$
$ts, ts! : TABLESCHEMA$
$l : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$
$columns, columns' : \mathbb{P}\, COLUMN$
$poc : ATTRIBUTEOfCLASS$
$primKey' : PRIMARYKEY$
$col2 : COLUMN$
$type : DTYPE$

$addEntityEL \gg entityToTableORM \gg addTableDB \gg [| \forall p : ATTRIBUTE \bullet p \in atts \Rightarrow$

removeAttribute

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$\Delta TABLESCHEMA$
$c? : CLASS$
$p? : ATTRIBUTE$
$poc : ATTRIBUTEOfCLASS$
$constraints : \mathbb{P}\, CONSTRAINT$
$col : COLUMN$

$removeAttributeEL$
$(p?.upper = One \land attributeToColumnORM \gg dropColumnDB) \lor$
$(p?.upper = Many \land attributeToTableORM \gg dropTableDB)$

removeAttributeWithNoData

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$\Delta TABLESCHEMA$
$c? : CLASS$
$p? : ATTRIBUTE$
$poc : ATTRIBUTEOfCLASS$
$constraints : \mathbb{P}\ CONSTRAINT$
$col : COLUMN$

$removeAttributeEL$
$(p?.upper = One \land attributeToColumnORM \gg dropEmptyColumnDB) \lor$
$(p?.upper = Many \land attributeToTableORM \gg dropEmptyTableDB)$

removeClass

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$c? : CLASS$
$label : LABEL$
$primKey, primKey' : PRIMARYKEY$
$atts : \mathbb{P}\ ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\ TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\ FOREIGNKEY$
$values, values' : \mathbb{P}\ DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns, columns' : \mathbb{P}\ COLUMN$
$col : COLUMN$
$ts, ts! : TABLESCHEMA$
$l, label' : LABEL$
$constraints : \mathbb{P}\ CONSTRAINT$
$poc : ATTRIBUTEOfCLASS$
$col2 : COLUMN$
$type : DTYPE$

$removeEntityEL \gg entityToTableORM \gg dropTableDB$

removeClassWithNoInstances

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$c? : CLASS$
$label : LABEL$
$primKey, primKey' : PRIMARYKEY$
$atts : \mathbb{P}\ ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\ TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\ FOREIGNKEY$
$values, values' : \mathbb{P}\ DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns, columns' : \mathbb{P}\ COLUMN$
$col : COLUMN$
$ts, ts! : TABLESCHEMA$
$l, label' : LABEL$
$constraints : \mathbb{P}\ CONSTRAINT$
$poc : ATTRIBUTEOfCLASS$
$col2 : COLUMN$
$type : DTYPE$

$entityToTableORM[ts/ts!]$
$selectAllData(ts, \theta DATABASE) = \varnothing$
$removeEntityEL$
$entityToTableORM \gg dropEmptyTableDB$

removeAssociation

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$a? : ASSOCIATION$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\ ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\ TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\ FOREIGNKEY$
$values, values' : \mathbb{P}\ DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\ COLUMN$
$col : COLUMN$
$ts, ts!, sourceSchema, targetSchema, table : TABLESCHEMA$
$l, name : LABEL$
$constraints : \mathbb{P}\ CONSTRAINT$
$c, d, sourceCLASS, targetCLASS : CLASS$
$fk1, fk2 : FOREIGNKEY$

$removeAssociationEL$
$a?.upper = One \Rightarrow assocToFkORM \gg dropForeignKeyDB \lor$
$a?.upper = Many \Rightarrow assocToTableORM \gg dropTableDB$

removeAssociationWithNoData

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$a? : ASSOCIATION$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\ ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\ TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\ FOREIGNKEY$
$values, values' : \mathbb{P}\ DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\ COLUMN$
$col : COLUMN$
$ts, ts!, sourceSchema, targetSchema, table : TABLESCHEMA$
$l, name : LABEL$
$constraints : \mathbb{P}\ CONSTRAINT$
$c, d, sourceCLASS, targetCLASS : CLASS$
$fk1, fk2 : FOREIGNKEY$

---

removeAssociationEL
$a?.upper = One \Rightarrow assocToFkORM \gg dropEmptyForeignKeyDB \lor$
$a?.upper = Many \Rightarrow assocToTableORM \gg dropEmptyTableDB$

moveAttribute

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$c? : CLASS$
$d? : CLASS$
$p? : ATTRIBUTE$
$map? : MAPPING$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\, ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\, TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY$
$values, values' : \mathbb{P}\, DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns, columns' : \mathbb{P}\, COLUMN$
$col : COLUMN$
$ts, targetSchema', ts! : TABLESCHEMA$
$l, label' : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$
$to : TABLESCHEMA$
$poc : ATTRIBUTEOfCLASS$
$primKey, primKey' : PRIMARYKEY$
$col2 : COLUMN$
$type : DTYPE$

$l = p?.label$
$c? \neq d?$
$d? \notin \mathrm{ran}(childParentRelation(c?, \theta ENTITIES)^+)$
$c? \notin \mathrm{ran}(childParentRelation(d?, \theta ENTITIES)^+)$
$entityToTableORM[ts/ts!]$
$entityToTableORM[d?/c?, to/ts!]$
$(p?.upper = One \Rightarrow$
$\quad addAttribute \gg attributeToColumnORM[col/col!] \gg$
$\quad (copyColumnDB[col/col?, ts/sourceSchema?, to/targetSchema?] \gg$
$\quad dropColumnDB[col/col?])) \lor$
$(p?.upper = Many \Rightarrow$
$\quad addAttribute \gg attributeToTableORM \gg$
$\quad changeAllReferencesInTable[to/target?] \gg removeAttribute[d?/c?])$

inlineClass

$\Delta ENTITIES$
$\Delta DATABASE$
$\Delta SOFTWARE$
$\Delta ASSOCIATION$
$c? : CLASS$
$d? : CLASS$
$map? : MAPPING$
$poc : ATTRIBUTEOfCLASS$
$to : TABLESCHEMA$
$atts : \mathbb{P}\, ATTRIBUTE$
$primKey : PRIMARYKEY$
$tables : \mathbb{P}\, TABLESCHEMA$
$columns, columns' : \mathbb{P}\, COLUMN$
$col : COLUMN$
$ts, targetSchema, targetSchema', ts!, tso, sourceSchema, table : TABLESCHEMA$
$l, name : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$
$primKey, primKey' : PRIMARYKEY$
$fk, fk1, fk2 : FOREIGNKEY$
$c, d, sourceCLASS, targetCLASS : CLASS$
$col2 : COLUMN$
$type : DTYPE$

$c? \in classes \land d? \in classes \land c? \neq d?$
$parentOf(c?, \theta ENTITIES) = NULLCLASS$
$children(c?, \theta ENTITIES) = \varnothing$
$\#attributesOf(c?, \theta(ENTITIES)) = 1$
$\forall a : ASSOCIATION \bullet a.source \neq c?$
$\forall q, r : ATTRIBUTE \bullet$
$\quad q \in attributesOf(c?, \theta(ENTITIES)) \land$
$\quad r \in attributesOf(d?, \theta(ENTITIES)) \Rightarrow q.label \neq r.label$
$\forall a, b : ASSOCIATION \bullet$
$\quad a.source = c? \land$
$\quad b.source = d? \Rightarrow a.label \neq b.label$
$[\!| \forall p : ATTRIBUTE \bullet$
$\quad p \in attributesOf(c?, \theta(ENTITIES)) \Rightarrow$
$\quad\; moveAttribute[p/p?]] \gg$
$[\!| \forall a : ASSOCIATION \bullet$
$\quad a.target = c? \Rightarrow changeAssociationDirectionEL[d?/target?, a/a?] \land$
$\quad\;\; changeReferenceInDB[a/a?, d?/target?]$
$removeClass]$

splitClass

$\Delta ENTITIES$
$\Delta DATABASE$
$\Delta TABLESCHEMA$
$\Delta SOFTWARE$
$l? : LABEL$
$p? : ATTRIBUTE$
$toSplit? : CLASS$
$label, l : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\ ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\ TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\ FOREIGNKEY$
$values, values' : \mathbb{P}\ DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\ COLUMN$
$col : COLUMN$
$ts, ts!, oldSchema, newSchema, targetSchema' : TABLESCHEMA$
$constraints : \mathbb{P}\ CONSTRAINT$
$g : CLASS$
$poc : ATTRIBUTEOfCLASS$
$to : TABLESCHEMA$
$atts, att : \mathbb{P}\ ATTRIBUTE$
$col2 : COLUMN$
$type : DTYPE$

$initEntity[g/c!]$
$att = \varnothing$
$addClass[g/c?, att/att?] \gg initMappingForSplit[toSplit?/old?, g/new?] \gg$
$moveAttribute[toSplit?/d?, g/c?]$

mergeClasses

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$c?, c_2? : CLASS$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\, ATTRIBUTE$
$schemas, schemas' , tables : \mathbb{P}\, TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY$
$values, values' : \mathbb{P}\, DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns, columns' : \mathbb{P}\, COLUMN$
$col : COLUMN$
$ts, ts2, ts! : TABLESCHEMA$
$l, label' : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$
$s : SEQUENCE$
$a : \mathbb{P}\, DATAVALUES$
$atts : \mathbb{P}\, ATTRIBUTE$
$primKey' : PRIMARYKEY$
$poc : ATTRIBUTEOfCLASS$
$col2 : COLUMN$
$type : DTYPE$

$attributesOf(c?, \theta ENTITIES) = attributesOf(c_2?, \theta ENTITIES)$
$associationsOf(c?, \theta ENTITIES) = associationsOf(c_2?, \theta ENTITIES)$
$parentOf(c?, \theta ENTITIES) = parentOf(c_2?, \theta ENTITIES)$
$parentOf(c?, \theta ENTITIES) = NULLCLASS$
$children(c?, \theta ENTITIES) = children(c_2?, \theta ENTITIES)$
$children(c?, \theta ENTITIES) = \varnothing$
$\forall\, a : ATTRIBUTE \bullet$
$\quad a \in attributesOf(c?, \theta ENTITIES) \Leftrightarrow a.upper = One$
$isReferenced(c?, \theta ENTITIES) = \varnothing$
$isReferenced(c_2?, \theta ENTITIES) = \varnothing$
$entityToTableORM[ts/ts!]$
$entityToTableORM[c_2?/c?, ts2/ts!]$
$[|\, \forall\, k, k_2, k_2' : DATAVALUES \bullet$
$\quad k.definition = ts \land k_2.definition = ts2 \land k \in values \land k_2 \in values$
$\quad \land\, k.key \neq k_2.key \Rightarrow (k_2'.definition = ts \land k_2' \notin values \land k_2' \in values' \land$
$\quad k \notin values') \lor$
$(\forall\, k, k_2, k_2' : DATAVALUES \bullet$
$\quad k.definition = ts \land k_2.definition = ts2 \land k \in values \land k_2 \in values$
$\quad \land\, k.key = k_2.key \Rightarrow k_2'.definition = ts \land k_2'.key.value = next(sequence))] \gg$
$removeClass[c_2?/c?]$

extractClass

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$c?, d : CLASS$
$p? : ATTRIBUTE$
$l? : LABEL$
$l : LABEL$
$u : CARDINALITY$
$o : BOOL$
$label, l, label', name : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\ ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\ TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\ FOREIGNKEY$
$values, values' : \mathbb{P}\ DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns, columns' : \mathbb{P}\ COLUMN$
$col : COLUMN$
$ts, ts!, oldSchema, newSchema, targetSchema', sourceSchema, targetSchema, table : TABLESCHEMA$
$constraints : \mathbb{P}\ CONSTRAINT$
$g, c, sourceCLASS, targetCLASS : CLASS$
$poc : ATTRIBUTEOfCLASS$
$to : TABLESCHEMA$
$atts, att : \mathbb{P}\ ATTRIBUTE$
$primKey' : PRIMARYKEY$
$a : ASSOCIATION$
$fk1, fk2 : FOREIGNKEY$
$col2 : COLUMN$
$type : DTYPE$
$map : MAPPING$

$l = p?.label$
$u = p?.upper$
$o = p?.optional$
$splitClass[c?/toSplit?, d/g] \gg$
$initAssociation[l/label?, u/upper?, o/optional?, c?/source?, d/target?, a/a!] \gg initMappingForSplit[c?/$
$addAssociation[a/a?]$

addParent

$\Delta ENTITIES$
$i? : INHERITANCE$
$map? : MAPPING$
$\Delta SOFTWARE$
$\Delta DATABASE$
$parent, child : CLASS$
$e : ENTITIES$
$s : SEQUENCE$
$a : \mathbb{P}\, DATAVALUES$
$atts : \mathbb{P}\, ATTRIBUTE$
$to, cts, pts, sourceSchema, targetSchema, targetSchema' : TABLESCHEMA$
$poc : ATTRIBUTEOfCLASS$
$label, label' : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\, ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\, TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY$
$values, values' : \mathbb{P}\, DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns, columns' : \mathbb{P}\, COLUMN$
$col : COLUMN$
$ts, ts! : TABLESCHEMA$
$l : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$
$primKey' : PRIMARYKEY$
$col2 : COLUMN$
$type : DTYPE$

$i?.parent = parent$
$i?.child = child$
$children(child, \theta ENTITIES) = \varnothing$
$entityToTableORM[child/c?, cts/ts!]$
$entityToTableORM[parent/c?, pts/ts!]$
$children(parent, \theta ENTITIES) = \varnothing \Rightarrow \quad [|\ constraints = \{NOTNULL\} \wedge$
$\quad initColumn[INSTANCEDEF/l?, constraints/constraints?] \gg addColumnDB[pts/ts?]] \gg$
$addEntityParentEL \gg [|\ \forall c : COLUMN \bullet c \in cts.columns \Rightarrow$
$\quad copyColumnDB[col/col?, cts/sourceSchema?, pts/targetSchema?] \gg$
$\quad dropColumnDB[col/col?, cts/ts?]] \gg$
$[|\ \forall fk : FOREIGNKEY;\ ts : TABLESCHEMA \bullet$
$\quad fk \in foreignKeys \wedge ts = fk.source \Rightarrow$
$\quad changeAllReferencesInTable[to/target?, ts/ts?] \gg$
$dropTableDB[cts/ts?]]$

removeParent

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$c? : CLASS$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\ ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\ TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\ FOREIGNKEY$
$values, values' : \mathbb{P}\ DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\ COLUMN$
$col : COLUMN$
$ts, ts!, targetSchema', table : TABLESCHEMA$
$l : LABEL$
$constraints : \mathbb{P}\ CONSTRAINT$
$map, me : MAPPING$
$poc : ATTRIBUTEOfCLASS$
$to, cts, pts, tso : TABLESCHEMA$
$atts : \mathbb{P}\ ATTRIBUTE$
$d, parent, sourceCLASS, targetCLASS, c : CLASS$
$label' : LABEL$
$primKey' : PRIMARYKEY$
$columns' : \mathbb{P}\ COLUMN$
$label, name : LABEL$
$constraints : \mathbb{P}\ CONSTRAINT$
$source, sourceSchema, targetSchema : TABLESCHEMA$
$fk1, fk2, fk : FOREIGNKEY$
$fkv, fkv' : FOREIGNKEYVALUE$
$col2 : COLUMN$
$type : DTYPE$

$children(c?, \theta ENTITIES) = \varnothing$
$parent = parentOf(c?, \theta ENTITIES)$
$removeEntityParentEL \gg entityToTableNoAttributesORM[cts/ts!] \gg addTableDB[cts/ts?] \gg entityT$
$copyColumnDB[col/col?, pts/sourceSchema?, cts/targetSchema?, map/map?] \gg$
$dropColumnDB[col/col?, pts/ts?] \gg$
$[| \forall t : TABLESCHEMA \bullet \quad \exists p : ATTRIBUTE \bullet p \in attributesOf(c?, \theta ENTITIES) \wedge attributeToTable$
$changeReferenceTableDB[t/ts?, c?/newTarget?, parent/oldTarget?, me/map?]] \gg [| \forall a : ASSOCIATI$
$[col : COLUMN \mid children(parent, \theta ENTITIES) = \varnothing \Rightarrow col.label = INSTANCEDEF \wedge dropColumnDB[$

pushDown

$\Delta ENTITIES$
$\Delta CLASS$
$p? : ATTRIBUTE$
$c : CLASS$
$poc : ATTRIBUTEOfCLASS$

---

pushAttributeDownEL

pushAttributeDownToClass

$\Delta ENTITIES$
$\Delta DATABASE$
$\Delta CLASS$
$\Delta CLASS$
$p? : ATTRIBUTE$
$parent, parent', child, child' : CLASS$
$poc : ATTRIBUTEOfCLASS$
$tab : TABLESCHEMA$
$primKey : PRIMARYKEY$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\, ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\, TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY$
$values, values' : \mathbb{P}\, DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns : \mathbb{P}\, COLUMN$
$col, col2 : COLUMN$
$type : DTYPE$
$ts, ts! : TABLESCHEMA$
$l : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$

$parent = \theta(CLASS)$
$parent' = \theta(CLASS)'$
$parent \in classes$
$child = \theta(CLASS)$
$child' = \theta(CLASS)'$
$child \in classes$
$p? \in attributesOf(parent, \theta(ENTITIES))$
$parent = parentOf(child, \theta(ENTITIES))$
$addAttributeEL[child/c?] \gg$
$removeAttributeEL[parent/c?] \gg$
$[|\ (p?.upper = One \Rightarrow \quad \forall\, dv, dv' : DATAVALUES \bullet$
$\quad entityToTableORM[parent/c?, tab/ts!] \wedge$
$\quad isInstanceOf(dv, child) \neq True \Rightarrow attributeToColumnORM[col/col!] \wedge$
$\quad\quad dv'.colValues = dv.colValues \setminus \{cv : COLUMNVALUE \mid$
$\quad\quad\quad cv.definition = col\})]$

pullUp

$\Delta ENTITIES$
$\Delta CLASS$
$parent? : CLASS$
$p? : ATTRIBUTE$
$poc : ATTRIBUTEOfCLASS$
$c, d : CLASS$

$p?.optional = True \Rightarrow \#children(parent?, \theta ENTITIES) = 1$
$pullAttributeUpEL$

pullCommonAttributeUp

$\Delta ENTITIES$
$c? : CLASS$
$p? : ATTRIBUTE$
$poc : ATTRIBUTEOfCLASS$
$c_p, c : CLASS$
$cs : \mathbb{P}\, CLASS$

$c_p = parentOf(c?, \theta(ENTITIES))$
$cs = \{c : CLASS \mid p? \in attributesOf(c, \theta(ENTITIES)) \land$
$\quad c \in children(c_p, \theta(ENTITIES))\}$
$addAttributeEL[c/c?]$
$\forall\, c : CLASS \bullet$
$\quad c \in cs \Rightarrow removeAttributeEL[c/c?]$

extractParent

$\Delta SOFTWARE$
$\Delta ENTITIES$
$\Delta DATABASE$
$parent, child? , child : CLASS$
$l? : LABEL$
$p? : ATTRIBUTE$
$e : ENTITIES$
$s : SEQUENCE$
$a : \mathbb{P}\, DATAVALUES$
$poc : ATTRIBUTEOfCLASS$
$atts : \mathbb{P}\, ATTRIBUTE$
$to : TABLESCHEMA$
$cts, pts : TABLESCHEMA$
$tsc, tsp, sourceSchema, targetSchema, targetSchema' : TABLESCHEMA$
$label : LABEL$
$primKey : PRIMARYKEY$
$atts : \mathbb{P}\, ATTRIBUTE$
$schemas, schemas', tables : \mathbb{P}\, TABLESCHEMA$
$foreignKeys, foreignKeys' : \mathbb{P}\, FOREIGNKEY$
$values, values' : \mathbb{P}\, DATAVALUES$
$sequence, sequence' : SEQUENCE$
$columns, columns' : \mathbb{P}\, COLUMN$
$col : COLUMN$
$ts, ts! : TABLESCHEMA$
$l, label' : LABEL$
$constraints : \mathbb{P}\, CONSTRAINT$
$primKey' : PRIMARYKEY$
$c, d : CLASS$
$att : \mathbb{P}\, ATTRIBUTE$
$col2 : COLUMN$
$type : DTYPE$

$parentOf(child?, \theta(ENTITIES)) = NULLCLASS$
$p? \in attributesOf(child?, \theta(ENTITIES))$
$att = \varnothing$
$initEntity[parent/c!]$
$addClass[parent/c?, att/att?] \gg initInheritance \gg$
$initMappingForExtractParent[parent/parent?] \gg$
$addParent[parent/parent?] \gg pullUp[parent/parent?]$